

Folded Shell Projectors and Virtual Optimization



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Introduction



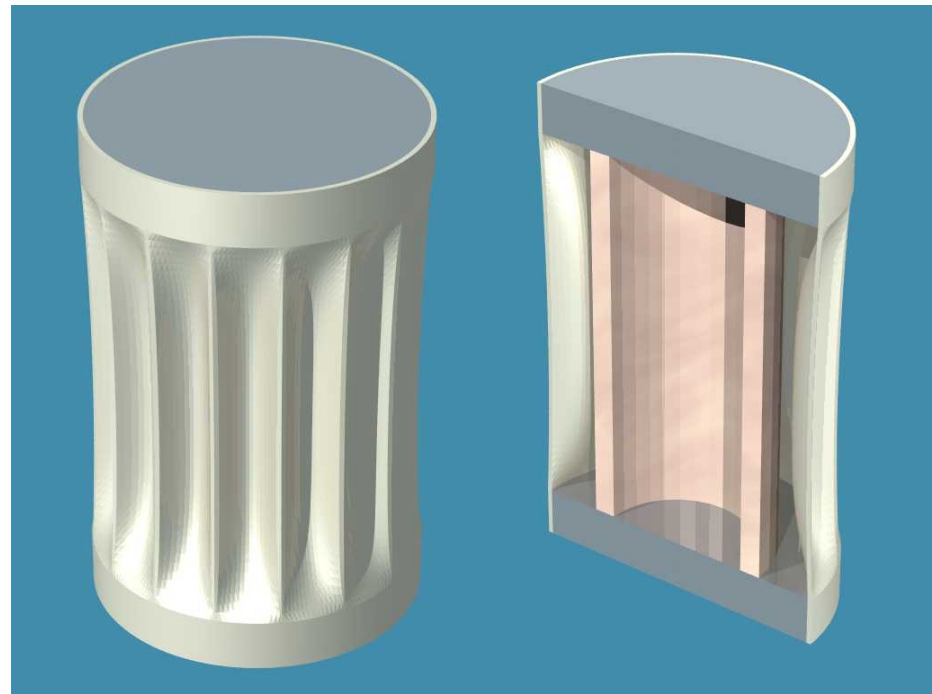
- **Present a study of the folded shell projector (FSP) described by Drozdowski and Purcell (DREA, Canada) at last year's ONR Transducer Workshop (April 2000)**
- **Describe a virtual optimization procedure for the FSP and other Naval transducers that combines the computational efficiency of PZFlex with a nonlinear least-squares inversion algorithm in a closed design loop**



Folded Shell Projector (FSP)

- Introduction -

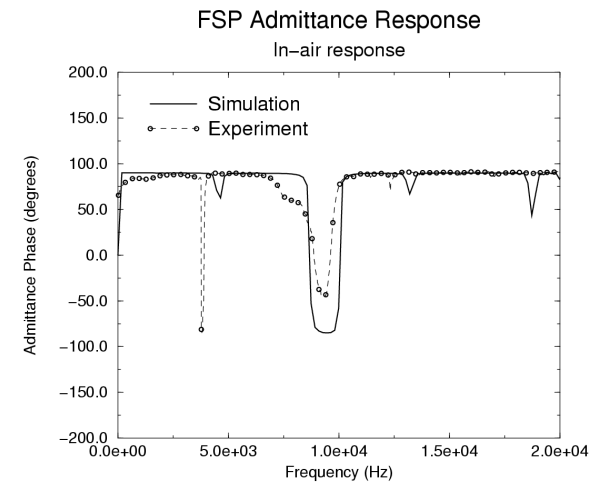
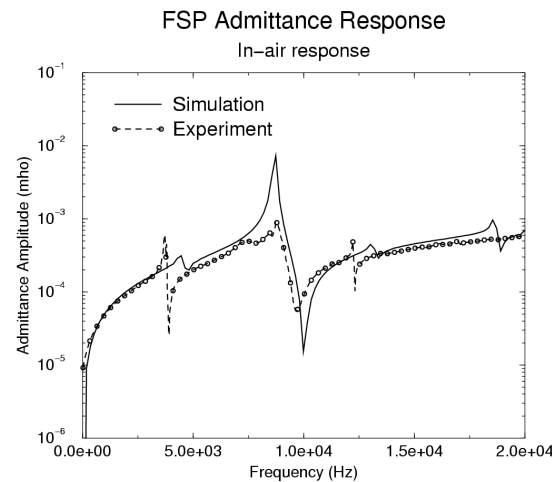
- Capped 'can' with longitudinal crimps to decouple circumferential stiffening from longitudinal bending
- Driven by a PZT stack or a Terfenol cylinder between stiff end caps
- Low frequency flextensional projector offers excellent pressure stability and avoids the fabrication and boot complexities of more traditional barrel-stave designs



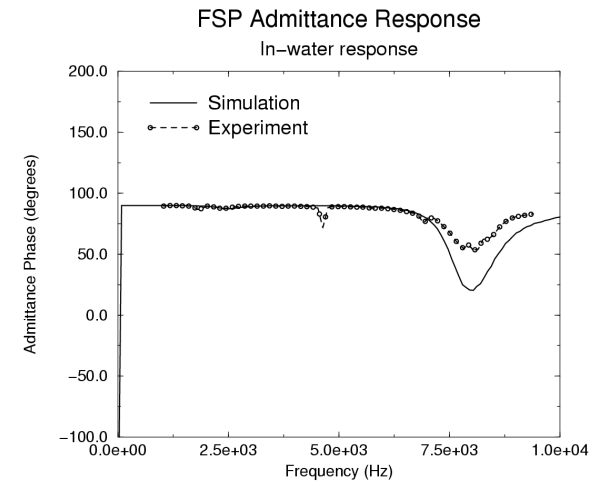
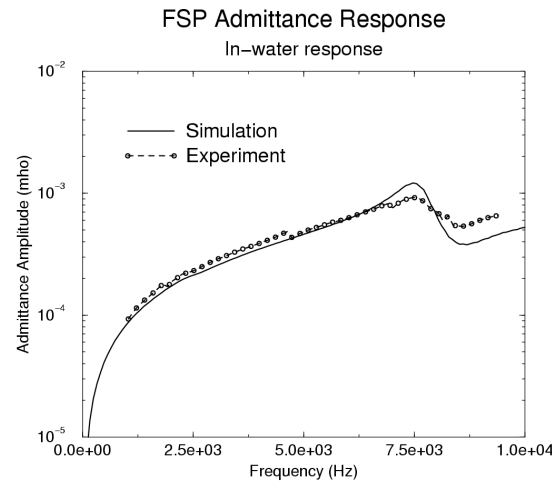
Folded Shell Projector (FSP)

- Finite element analysis & experimental results-

In-air admittance



In-water admittance



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Folded Shell Projector (FSP)

- Finite element analysis & experimental results -

■ Mode shape at 1st resonance



0°



180°



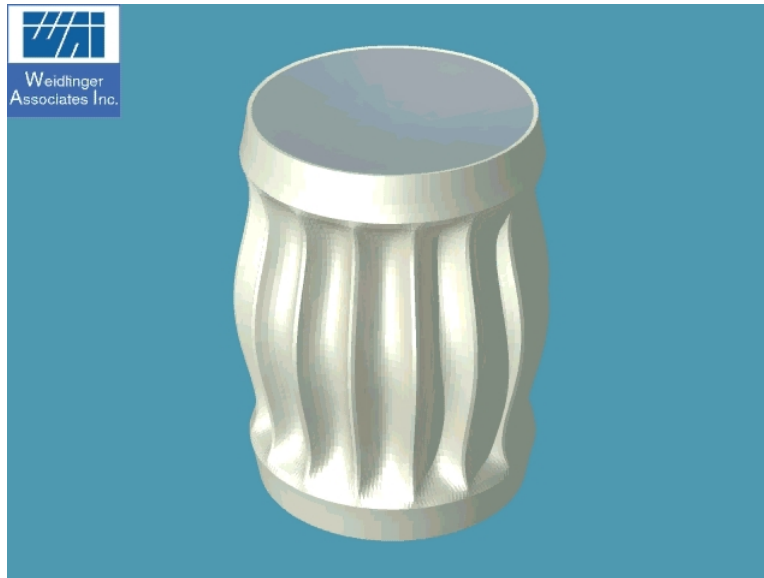
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Folded Shell Projector (FSP)

- Finite element analysis & experimental results (cont.) -

■ Mode shape at 2nd resonance



0°



180°



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Virtual Prototyping and Optimization

- **Naval transducer designs are becoming more complex and are often non-linear in nature**
 - Expensive to prototype using conventional tooling for one-of-kind studies
 - DREA in Canada have developed laser consolidation fabrication processes for *functional* rapid prototyping of the FSP shell
- **Virtual prototyping and optimization is a complementary approach that can help minimize prototyping costs**
 - Replaces many experiments - will never replace all experiments
 - Appropriate when experiments are costly or when time-to-market is critical



Optimization

- Application areas -

- **Characterization of piezoelectric materials**
- **Tonpilz transducers for high-power ultrasonic cleaning applications**
- **Broadband biomedical transducer arrays with multiple-matching layers**



Optimization

- Overview -

- **Ultimate goal is systematic device optimization using a forward computer model coupled to an inversion algorithm in a closed loop**
 - Use PZFlex as the function evaluator
 - Use PRAXIS as the optimization tool
- **Search algorithms can identify optimal solutions in significantly less time than it would take using an OFAT (one factor at a time) type approach**
- **Need to identify appropriate figures of merit**
 - Transducer designer is still in complete control of design direction
 - Choice of the appropriate target functions requires careful consideration



Optimization

- Function evaluator -



■ PZFLEX

- Explicit time-domain finite elements
- Transient (broadband) capability
- Permits large-scale, 3D models (including device & environment)
- Nonlinearity readily included in analysis

■ Approach is shown to be feasible on desktop PCs

- In the hands of a new generation of transducer designers, approach can yield better device performance at reduced cost in less time



Optimization

- Inversion algorithm -



- **Nonlinear least squares inversion algorithm**
 - Based on Brent's minimization code, PRAXIS
 - Does not require analytic derivatives nor approximate them via finite differences
 - Particularly useful when evaluation of object function is time consuming



Optimization

- Implementation of bound constraints -

- **PRAXIS is an unconstrained optimization code**

- But, the problems considered here are constrained

- Each parameter, α_i , is subject to simple bound-constraints

$$\underline{\alpha_i} \leq \alpha_i \leq \overline{\alpha_i}$$

- Change of variable to χ_i transforms the problem to an unconstrained one

$$\chi_i = -\ln\left(\frac{\overline{\alpha_i} - \alpha_i}{\alpha_i - \underline{\alpha_i}}\right)$$

- Corresponding inverse transformation

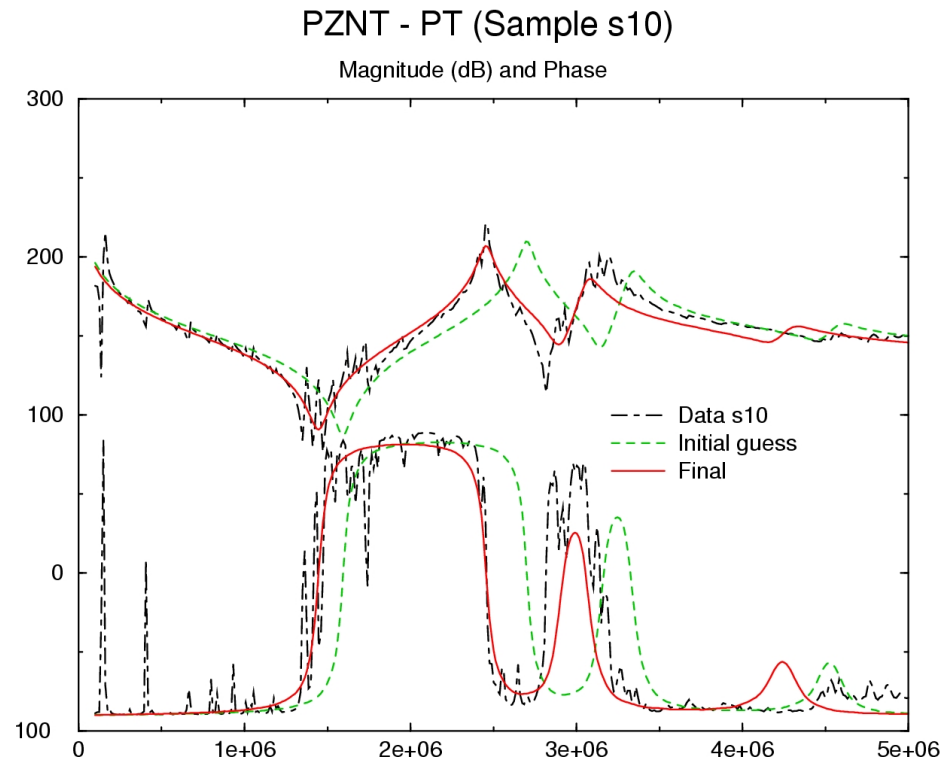
$$\alpha_i = \frac{\underline{\alpha_i}}{(1 + \exp(\chi_i))} + \frac{\overline{\alpha_i}}{(1 + \exp(-\chi_i))}$$



Optimization

Example #1 - Piezoelectric material characterization (PZNT-PT)

- The 12 unknown material constants are typically determined using different experimental samples that operate in different frequency regimes
- Using the nominal set of material properties, the values were refined using an iterative virtual optimization procedure



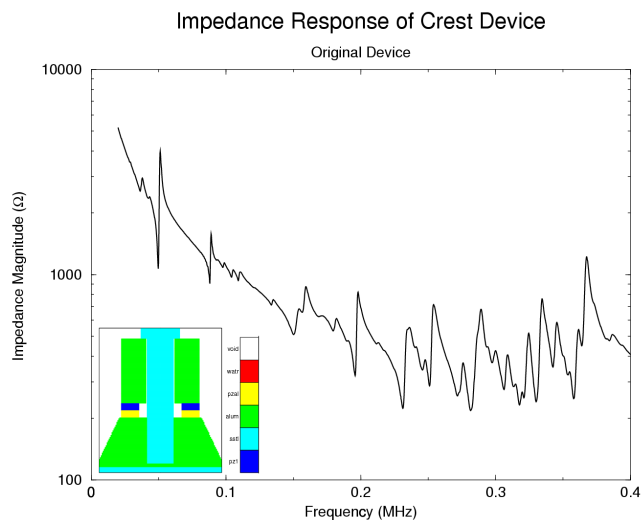
Note: The spurious resonant behavior can be attributed to localized changes in material composition and domain structure - these resonances would NOT exist if the material was homogenous.

Optimization

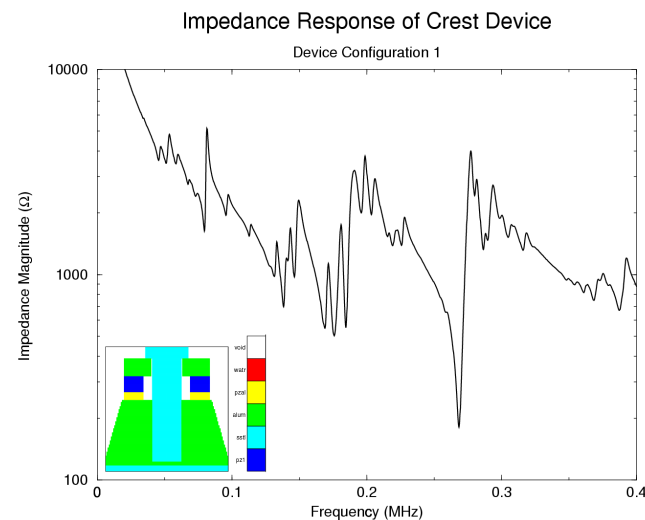
Example #2 - Tonpilz transducer for ultrasonic cleaning

- **Objective:** Maximize power output from Tonpilz transducer used in ultrasonic cleaning applications
- **Parameters varied:** ceramic thickness, head-mass & tail-mass

Before



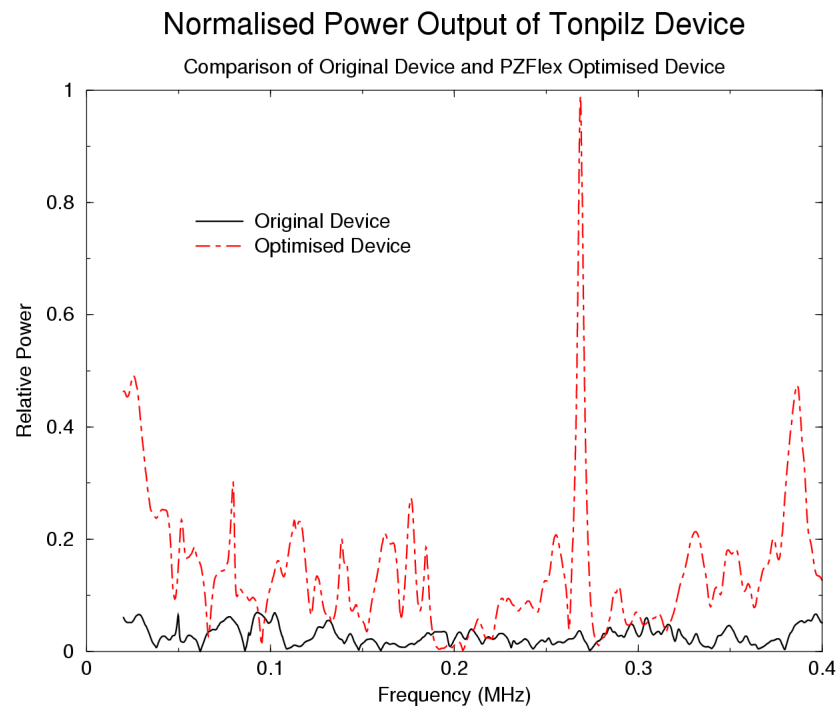
After



Optimization

Example #2 - Tonpiliz transducer for ultrasonic cleaning (cont.)

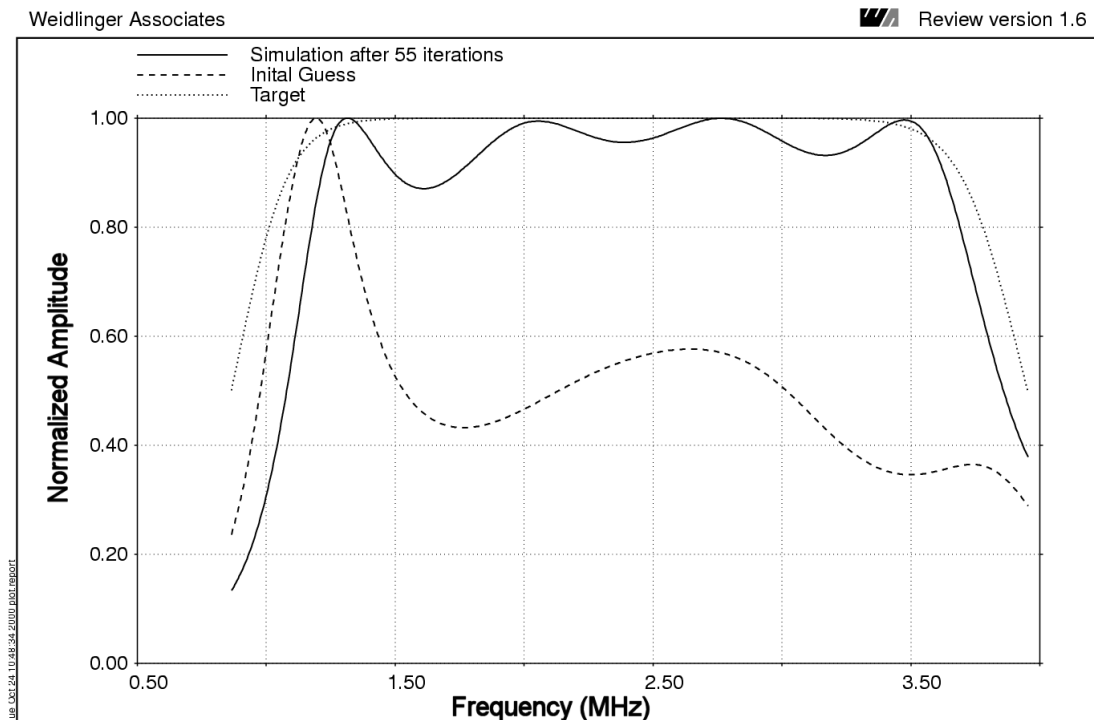
- After the iterative optimization process, power output has improved significantly
- A very strong resonance has been identified at 270kHz, which falls within the frequency range of interest (200-300kHz)



Optimization

Example #3 - Structural optimization for broadband imaging array

- Material properties and device dimensions initially selected based on “rules of thumb”
- A broadband target functional is specified
- After 55 iterations, system performance has improved dramatically



Conclusions



- **Virtual optimization allows more rapid convergence towards optimal solution than possible via a simple sweep of multi-dimensional parameter space**
- **Choice of target function (figure-of-merit) can prove problematic and requires skill on the part of the designer**
- **PRAXIS proves effective for applications where evaluation of object function is time consuming e.g. large 3D nonlinear transducer structures**
- **Virtual prototyping and optimization leverage R&D dollars, allowing novel designs to be explored more readily, and transforming innovative ideas into optimal designs more quickly and cheaply**

